by the glacial dam which I have supposed to have existed at Cincinnati. The facts had so impressed Mr. Squier that before knowing of my discoveries he had come to the conclusion that there must have been some such barrier as I have supposed. (See *Science*, Sept. 28, 1883.)

Strong as these confirmations are, it is important that the hypothesis of an ice dam should be verified by much wider observations in the field. All along the Ohio river, and in all its tributaries above Cincinnati, there should be found numerous facts, explicable only by this theory; while the absence of terraces of a corresponding level upon the eastern side of the Alleghenies, to which Professor Lesley has called attention, excludes the hypothesis that these high terraces in the Upper Ohio are due to a general Champlain subsidence.

Nor must the phenomena below Cincinnati be overlooked. During the summer of 1883, I continued my investigations into Southern Indiana to the Illinois line in Posey county. But I will not here speak in detail of the results attained. The problem of determining the southern limit of the glaciated area of this region, however, has been complicated by what I supposed to be the results of the Champlain subsidence, amounting to five hundred feet or more in the Mississippi valley. Here, for the first time in my western investigations, I have encountered the loess overlapping and intermingling with the terminal deposits of the glaciated area in a very interesting and puzzling manner. I hope during another summer to get additional light upon the subject. Meanwhile, I am anxious to obtain any information or instruction which the experience or wisdom of other investigators may be able to furnish me.

——:o:——

THE STRUCTURE OF THE TRACHEÆ OF INSECTS.

BY PROFESSOR G. MACLOSKIE, D.SC., LL.D.

1. Historical.—Blanchard's theory of two tracheal membranes with an interposed spiral thread, and of peritracheal circulation, though it was accepted by Louis Agassiz and some other authorities, may be set aside as obsolete. It was well refuted by Joly; and Claparède, in refuting its author's cognate theory of a complex

vascular system in spiders, showed that in both groups the circulation is essentially lacunar.[1]

Recent investigation has established the doctrine that the tracheæ and also the trachea-like salivary ducts are chitinous products of ingrowing processes of the epidermis. Bütschli deems them segmental paired invaginations of the epidermis, while Weismann finds that the tracheal wall is an intima secreted by ingrowing rows of cells, just as the chitinous cuticle is secreted by epidermal cells.[2] These discoveries are of fundamental importance, and must underlie the true theory of the nature of tracheal structures.

The views of some other investigators seem to me not so well established. Meyer, for example, finding that the intima (the name here used to designate the chitinous wall of the trachea) arises as a homogeneous membrane, holds that it subsequently splits so as to give off a spiral thread, and that the larger trunks have a double membrane external to the spiral.[3] Carl Chun supposes that the spiral thread is a true chitine layer, and not merely a thickening product of the intima, and superadds a splitting of the intima into a double membrane.[4] C. S. Minot represents the spiral filaments as solid threads imbedded in the substance of the chitinous intima, and adds some good observations as to the spiral threads (sometimes two to five or six together) ending after a few turns round the trachea, "the single threads terminate not abruptly but by tapering down to a point and so disappearing."[5] None of these observers seem to see, much less to grapple with the difficulty of conceiving how the spiral filament or anything else can be formed external (morphologically) to the chitinous secretion of the epidermis, or how such chitinous outgrowths can split after they are once formed.

2. *Pseudotracheæ of Muscidæ.*—In examining the proboscis of

[1] Blanchard in *Ann. d. Sci. Nat.*, Ser. 3, Vol. IX (1848), and *Ann. and Mag. Nat. Hist.*, Ser. I, Vol. XX. Joly in *Ann. d. Sci. Nat.*, Ser. 3, Vol. XII (1849). L. Agassiz in Proc. Amer. Ass. Adv. Sci., 1850. Claparède in *Ann. d. Sci. Nat.*, Ser. 5, Vol. II (1864).

[2] *Zeit. f. Wiss. Zool.*, XIII, XIV, XVI (1863–1866, Weismann), XX (1870. Bütschli).

[3] *Zeit. f. Wiss. Zool.*, I (1848).

[4] Inaugural dissert., "U. d. Bau u. der Rectaldrüsen b. d. Insekten," Frankfurt, 1876.

[5] U. S. Entomol. Comm. on Locusts, Report II, p. 192 (1880), and *Recherchés histologiques sur les trachées de l'Hydrophilus piceus*, in Archiv. de Physiol. Expt. 1876.

the housefly, some years ago, I made a discovery, the important bearings of which were easy to appreciate; but I did not refer to it in the paper then issued, as I wished to test it more fully. I found that the scraping-tubes (pseudotracheæ) of this organ are flanked by chitinous thickenings of the cuticle, that these thickenings are enfolded or wrinkled so as to resemble the C-like semitubes which serve as an inner skeleton for the pseudotracheæ. The enfolded parts can be flattened out with the needle, and when liberated they at once spring back to their normal crenulated condition (Fig. 1, C). This suggests that the *pseudotracheæ* (P) *are likewise thickened crenulations* of the chitinous membrane with which they are continuous.[1]

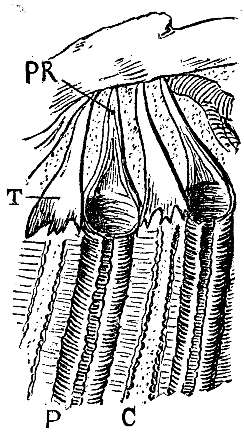

FIG. 1.—From distiproboscis of housefly (*Musca domestica*). P, two pseudotracheæ, with (C) bordering crenulations, and (T) two teeth, PR, basal roots of two pseudotracheæ, inserted in a transverse bar.

This doctrine receives unexpected support from Kraepelin's elaborate paper, just published, on the proboscis of Musca.[2] Kraepelin accepts the views published by myself, and confirmed by Dimmock, as to the general structure of the proboscis, at the same time adding largely to our knowledge of the anatomy of its parts. He also adopts the explanation of its protrusion by the injection of air. He has made the curious discovery that the teeth (T) planted between the roots of the pseudotracheæ, and likewise that these roots themselves, are formed by secondary foldings of the membrane. If he had followed out this observation he would have come to the conclusion that the entire pseudotracheæ, being crenulatious at the outset, are so throughout. This is the conclusion that I formerly reached, as stated above, from an independent line of investigation, and hence I may take it as proven that these structures, so long a subject of interest, have now found their true explanation.

[1] For a description of these parts see my paper on the "Proboscis of the House-fly," AMER. NATURALIST, 1880, p. 153.

[2] Karl Kraepelin, Hamburg. "Zur Anatomie u. Physiol. des Rüssels von Musca," with 2 plates (1883). His figure has three rows of 2-cusped teeth, and probably is drawn from the blowfly (*M. vomitaria*), whilst mine is from the housefly, which has only one or two rows of 3-cusped teeth.

3. Wall of Tracheæ.—This discovery leads to wider results. The pseudotracheæ so closely resemble the salivary duct and the proper tracheæ that all these structures have been frequently confounded together. The pseudotracheæ being surface-productions are open externally by a longitudinal slit. The salivary duct and proper tracheæ, being internal structures, do not admit of a lateral fissure, but they are ingrowths from the surface, and are morphologically of the same nature as the pseudotracheæ. Hence we may expect them to be produced on the same principle. If the pseudotracheæ are demonstrated to be thickened crenulations of the external cuticle, we are led to ask whether the spirals of the proper tracheæ and of the salivary duct are not crenulated thickenings of the intima.

The fragment of a trachea of a centipede (Fig. 2) bears out this interpretation. Above A is a rent with a small fragment of the membrane supporting relics of spirals, which are probably crenulations of the membrane, gradually losing themselves below. This is very unlike what would appear if the spirals were independent structures. Whenever the spiral separates from the membrane the separation is artificial, as the membrane is easily rent. We never find here what is common in plants, the spiral unrolling with the membrane remaining intact. In fact, membrane and spiral here appear to be continuations of each other, the membrane thickening and turning in to form a fold, somewhat after the pattern of the bellows of an accordeon. Minot's observations about the spirals often coming away, several together, and about their tapering down to a point and gradually disappearing, find their explanation in this. At the origin of branches (Fig. 2) the arrangement of the spirals agrees with this view rather than with the supposition of independent threads, and is identical with the pattern of branching at the " catch-drain " of the pseudotracheæ, which we have shown to be crenulations.

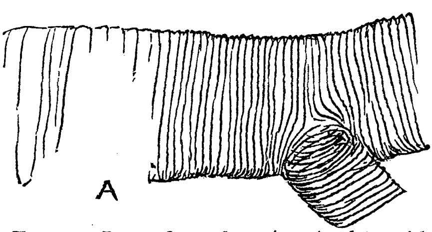

FIG. 2.—Part of trachea (centipede) with origin of branch.

A result of this explanation is, that the spirals themselves are fine tubules, externally opening by a fissure along their course.

They are so minute that we need not be surprised if direct observation has hitherto failed to detect this structure. A cross section of them in my possession (prepared by W. M. Rankin) seems to me to confirm this view; but the outside diameter of the spiral is only .0025^{mm} (about a twenty-thousandth of an inch), and interferences by diffraction lessen the value of direct observations except as to general outline.[1] I think that I can also see evidence of a lumen within the spiral, and of the fissure, in stained specimens of tracheæ prepared in the usual way.[2] Carl Chun's figure, though not so understood by its author, is in accordance with our view (Fig. 3). What he supposes to be solid fibers cannot arise in the way suggested by him, inside and independently of the intima, which is really the boundary of the insect's body. The connecting membrane (M) after reaching the spiral (which is probably hollow) bends in, becoming in fact the wall of the spiral, and on returning to the surface beyond the fissure, is continued as a connecting membrane to the next spiral. What he regards as a superficial ridge on the spirals is here supposed to be the optical expression of the external fissure. I think I have also got the explanation of the "outer membrane of later origin" represented at M². It is the first appearance of a new intima prepared to replace the functioning one after the process of molting.

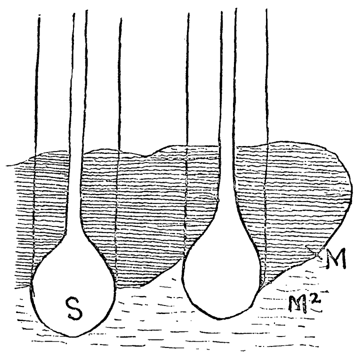

FIG. 3.—Cross-section of two spirals (S) from larva of Eristalis. M, a fragment of connecting membrane; M², outer membrane of later origin. After Chun.

The mode of genesis of the spirals has been found by different observers to be first by the formation of homogeneous membrane. This condition persists in fine branches and also in large air-sacs (in these, however, striation is usual). The homogeneous membrane soon becomes transversely striated by incipient crenulation. In a larva we can easily see new tracheæ in the striated condition

[1] The margin of what I take to be their lumen appears to me too sharp to be explained by refraction in solid fibrils.

[2] In stained specimens viewed, as Fig. A, the circle of light at the margin of the spirals is so bright and well defined as to indicate an inner cavity.

enclosing older ones with well-developed spirals; a tube inside of a tube, the contrast between striæ and spirals indicating the course by which increasing crenulation with thickening is turning the smooth membranous tube into the definitely strengthened trachea.

4. Mode of Aëration.—The chitinous walls of the tracheæ are supposed to permit the transmission of aïr to the surrounding blood, but not the passage of fluids. If we bear in remembrance that the air within them is dry (*sc.*, not dissolved in any fluid), I suspect that the direct passage through the wall is imaginary. Gegenbaur thinks that the fine extremities of the tracheæ may play some part in the function of aëration, and a consideration of the terminals of the tracheal branchlets may well make us ask if they do not perform the chief part. Boudelot has fixed the seat of the respiratory movements in the abdominal nerves, and therefore in the abdominal muscular movements.[1] As the abdomen expands and contracts, the tracheal trunks rhythmically enlarge and diminish, causing inspirations and expirations of air; a partial vacuum and pressure being alternately produced around the trunks. The structure of the spirals indicated above explains what was long a mystery to me, how chitine, which is flexible but not tensile, can secure the enlargement and reduction of volume essential to a tidal movement of air. The opening and closing of the spiral crenulations, with widening and narrowing of the external fissures, respond to the oscillations of pressure, and hence the variations of volume and the movements of air.

The air reaching the numerous branchlets of the tracheæ, supplies directly all the important tissues, the digestive canal, glands, nerves, limbs, eyes, mouth-parts, &c. The branches have no chitine at their extremities, enter directly into what L. Agassiz described (*loc. cit.*) as "bags, which when highly magnified look like small lungs; the branchlets losing the spiral thread when they enter these lungs." Weismann describes and figures these terminals as long spindle-cells having a fine elastic intima within them; and states that in the young larva they are filled with air. Max Schultze has shown how in the glow-worm (*Lampyris splendidula*) the terminal cells of the tracheæ are stellate, and are abundant at the fat-bodies which by a process of slow combustion

[1] *Ann. d. Sci. Nat.*, Ser. 5, Vol. II (1864).

cause luminosity (Fig. 4). It may be pertinent to cite Quatrefages' description of the luminosity of some marine animals.[1] I have observed that the light flashes in jets along the somites of these worms as if the segmental organs had something to do with its production and with the function of respiration. I have also shown that in the housefly the air-cells in the proboscis expand at each act of respiration.[2] It would thus appear that during inspiration the air is driven into the tracheal end-cells, as into the chambers of our own lungs, and that in this way the tissues are directly aërated. The slower process of aëration by the intervention of the blood may suffice in some larvæ, as in Crustacea, but the chief function of the blood of insects seems to be the conduction of food from the intestinal walls to the various organs.

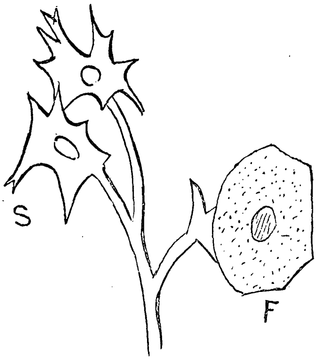

FIG. 4.—Stellate terminals (S) of tracheæ; F, luminous fat cells. After Schultze.

To sum up. The tracheæ of insects and similar organs are supported by chitinous fibers which are crenulations accompanied by thickening of the chitinous intima with which they remain continuous; their dorsal fissure and flexibility providing for the enlargement and reduction of the cavity; and the oxygenation of the tissues has its seat chiefly at the extremity of the tracheal branches, and not by diffusion from the tracheal trunks into the blood.

——:o:——

AGRICULTURAL BOTANY.

BY E. LEWIS STURTEVANT, M.D.

THE secret of classification consists in the understanding of the motive, of which form and structure are exponents. The natural motive of plants is to secure existence and perpetuation, and parts and habits are and have been so formulated as to compass this object as against difficulties of very varied character. Each individual plant is in a state of unstable equilibrium, ever

[1] *Ann. d. Sci. Nat.*, Vol. XIX (1843).

[2] *Psyche*, No. 100 (Aug., 1882).